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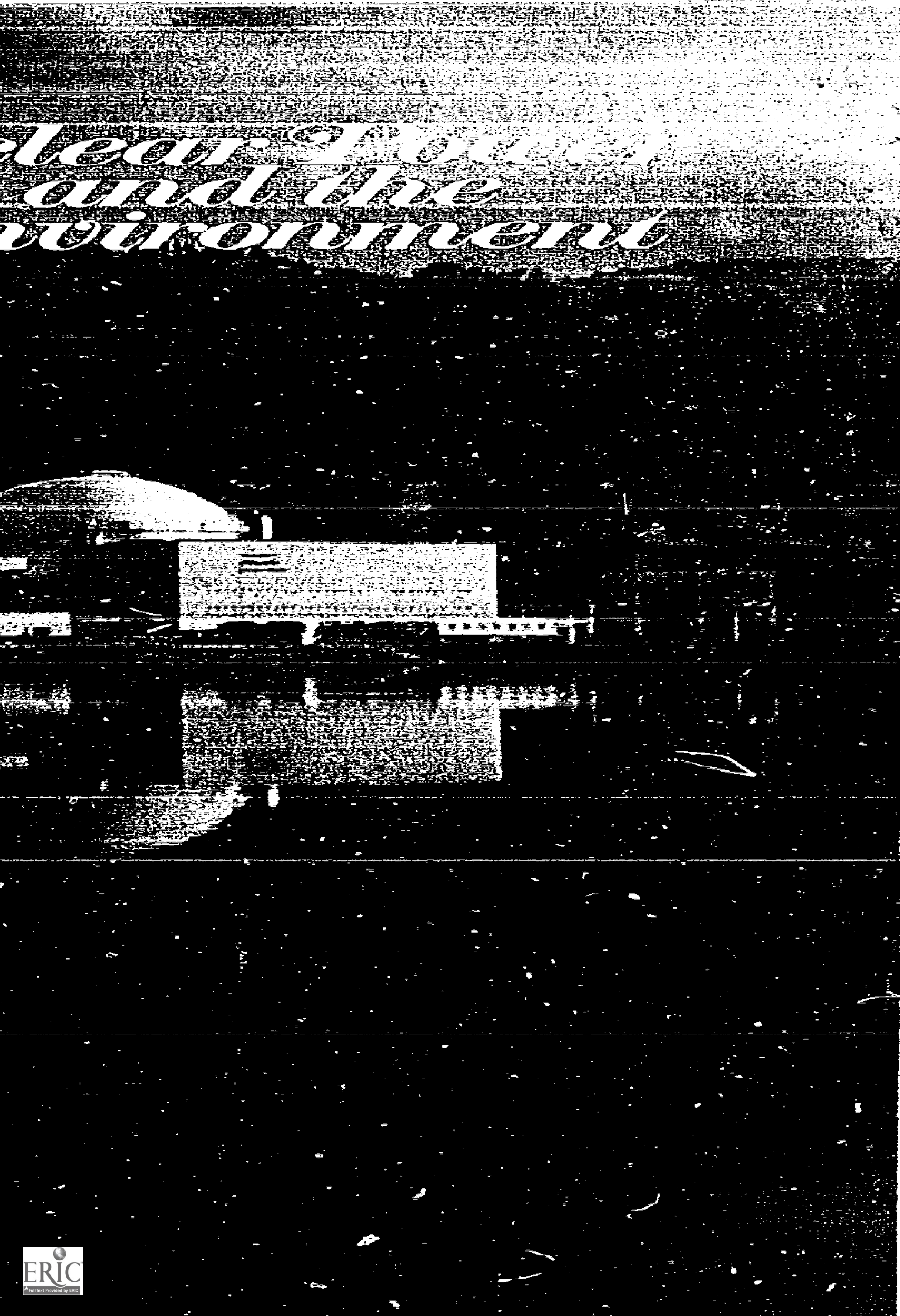
ABSTRACT

This booklet is one of the booklets in the "Understanding the Atom Series" published by the U. S. Atomic Energy Commission for high school science teachers and their students. Discussion concentrates on the radiological and thermal aspects of the environmental effects of nuclear power plants; on the procedures followed by the Atomic Energy Commission (AEC) to minimize the impact of nuclear plants on man and his environment; and on the research conducted by the AEC and others to further expand our knowledge. Numerous photographs and diagrams are utilized and a list of suggested references is included. (Author/PR)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One of a series on
UNDERSTANDING THE ATOM

UNITED STATES
ATOMIC ENERGY COMMISSION

Dr. Glenn T. Seaborg, Chairman
James T. Ramey
Wilfrid E. Johnson
Dr. Theos J. Thompson
Dr. Clarence E. Larson

Nuclear energy is playing a vital role in the life of every man, woman, and child in the United States today. In the years ahead it will affect increasingly all the peoples of the earth. It is essential that all Americans gain an understanding of this vital force if they are to discharge thoughtfully their responsibilities as citizens and if they are to realize fully the myriad benefits that nuclear energy offers them.

The United States Atomic Energy Commission provides this booklet on nuclear power and the environment to help you achieve such understanding.

Edward J. Brunenkant

EDWARD J. BRUNENKANT, *Director*
Division of Technical Information

About the cover:
The Yankee Nuclear Power Station in Rowe, Massachusetts, began commercial operation in 1961.

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Nuclear Power and the Environment

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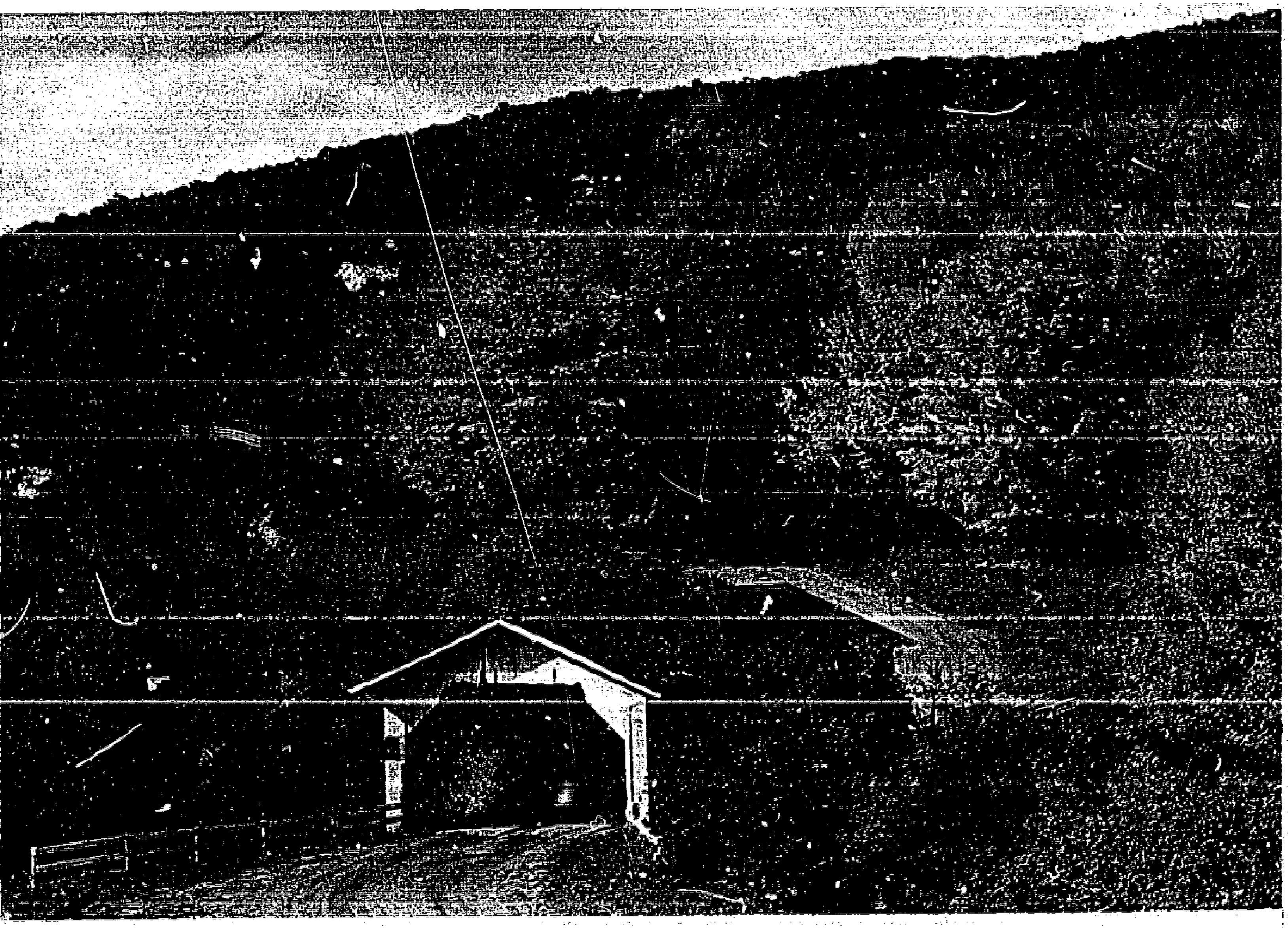


Covered bridge in Montgomery, Vermont.

Nuclear Power and the Environment

SUMMARY

Increasing concern is being expressed about the environmental effects of electrical generating plants, both conventional and nuclear. The AEC has prepared this report to discuss for nuclear power plants those matters that appear to be the basis for this concern, and, in the process, hopefully to put them into better perspective.

This report concentrates on a discussion of the radiological and thermal aspects of the environmental effects of nuclear power plants; on the procedures followed by the AEC to minimize the impact of nuclear plants on man and his environment; and on the research conducted by the AEC and others to further expand our knowledge.

Electric power is vital to the health, comfort, and economic well-being of the American people. Although some might consider it as just a convenience, power is essential to our modern society. Electric power is used to heat and cool our homes; to provide lighting; to run our industries; and to assist us in performing a multitude of other tasks. We are completely dependent upon electric power. Those who experienced the massive Northeast blackout of 1965 or other more recent power failures will bear witness to this fact.

Electric power requirements in this country have been doubling about every ten years. Future expansion is expected to continue in much the same pattern. Steam electric power plants, whether fossil fired or nuclear, must be relied upon in the main to meet these ever increasing power needs. There are relatively few economical sites available for hydroelectric plants. Efforts to develop acceptable alternate systems for meeting our bulk power needs are unlikely to prove successful in the foreseeable future.

The use of steam electric power plants will inevitably have an impact on the environment. The fossil fuel plants accelerate the exhaustion of irreplaceable resources; add heat to the air and water; consume oxygen and add carbon dioxide, sulfur dioxide, and other gaseous and particulate matter to the environment. Nuclear power reactors also add waste heat to the air and water and, in addition, add low levels of radioactivity to the environment.

The development of nuclear reactor technology in the United States has been characterized by an overriding concern for the health and safety of the public and for the protection of the environment. The safety record in comparison to other industrial activities has been excellent. No member of the general public has received a radiation exposure in excess of prescribed standards as the result of operation of any type of civilian nuclear power plant in the United States. As a matter of fact, no accidents of any type affecting the general public have occurred in any civilian nuclear power plant in the United States.[1]

During operation, nuclear power plants are permitted to release, under well controlled and carefully monitored conditions, low levels of radioactivity. Experience to date with licensed operating power reactors shows that such levels of radioactivity have been a small percentage of levels permitted to be released under AEC regulations. These AEC limits are based on guides developed by the Federal Radiation Council and approved by the President for the use of Federal agencies. In evaluating the acceptable risk from radiation exposures, the Council uses the best technical expertise in the field, and takes into account the recommendations of the National Council on Radiation Protection and Measurement and the International Commission on Radiological Protection.

We are all continuously exposed to radiation from decay

[1] Since the beginning of the atomic energy program in 1943, seven U.S. workers have died in radiation-connected accidents. Of these seven, three occurred in an AEC-owned experimental reactor (SL–1) at a remote testing station in Idaho, two were from criticality accidents in the weapons program, and two occurred in nuclear fuel processing plants. This record compares most favorably with similar development and industrial activities.

Samples of freshwater organisms are gathered at the AEC's Hanford facility as part of continuing environmental studies.

of radioactive isotopes[2] normally found in our body tissues and from natural earth and cosmic ray sources. This is termed background radiation,[3] and all humans and other species have been subjected to such radiations throughout history. Monitoring studies of radioactivity and radiation levels in areas adjacent to operating power reactors show that, in general, the annual additional radiation exposure contributed by nuclear power plants is comparable to the natural differences in radiation background commonly observed between geographic locations separated by several miles.

All steam electric generating plants—whether fossil fueled or nuclear—must release heat to the environment as an inevitable consequence of producing useful electricity. The least costly and most widely used method of disposing of this heat is to take large amounts of cooling water from nearby rivers, lakes, estuaries, or the ocean, circulate it through the power

[2] A radioactive isotope (or radioisotope) is an unstable form of an element that decays or disintegrates spontaneously, emitting radiation. For definitions of these and other unfamiliar words, see *Nuclear Terms, A Brief Glossary*, another booklet in this series.

[3] See *The Natural Radiation Environment*, another booklet in this series.

plant cooling system, and return it to the source body of water. Thermal effects is a term used to describe the impact that the heated water may have on the source body of water. The thermal effects may be detrimental, beneficial, or insignificant depending upon the specific site and measures taken in the design and operation of the plant.

The current generation of nuclear power plants produce more waste heat than modern fossil units of the same generating capacity. With the advanced reactors now under development, however, this disparity between nuclear and fossil plants will be greatly reduced.

Considerable work on the problems associated with disposal of waste heat from power plants has been conducted. To a significant extent, the problems of thermal effects are understood and they are manageable. Continuing research and development will bring further improvements in heat removal systems and further increase our understanding of thermal effects.

The AEC has been studying the effects of reactor heat

Banding of wild geese to study environmental effects of radionuclides on wildlife.

added to the Columbia River since 1946. The AEC is also sponsoring thermal effects research at its Pacific Northwest Laboratories, at the Chesapeake Bay Institute of Johns Hopkins University and at the University of Miami in Florida. The AEC plans to increase this program significantly in view of the large number of plants to be built in the coming years.

Several other Federal agencies, notably the Federal Water Pollution Control Administration, are conducting extensive research on thermal effects. The electric utilities are also sponsoring much work—particularly in connection with specific power plant sites.

During the past 25 years, the AEC has gained considerable knowledge and experience from the operation of nuclear reactors at sites in Washington (Hanford) and South Carolina (Savannah River). This experience can be applied to evaluation of the environmental effects of commercial nuclear power stations. It is significant and encouraging that no adverse environmental effects have been detected in these two instances.

ELECTRIC POWER GROWTH

The increasing demand for electric power can be attributed to a number of factors. The population growth, of course, has been important but it is only part of the story. Electric power usage per person has been increasing at a much faster rate than the population. Industry usage has grown. Electricity has been used in many new areas such as residential air conditioning and space heating.

Total consumption of electrical energy in the United States quadrupled between 1950 and 1968, while the population increased by one-third. The consumption per capita rose in that period from 2000 to 6500 kilowatt hours per year. The estimated per capita consumption in 1980 is some 11,500 kilowatt hours and about 25,000 kilowatt hours by the year 2000.

The projected growth of generating capacity in the eleven Northeastern states [4] illustrates these mounting electric

[4] Vermont, New Hampshire, Connecticut, Rhode Island, Massachusetts, Delaware, New Jersey, New York, Pennsylvania, Maine, and Maryland.

U.S. ELECTRIC UTILITY POWER STATISTICS RELATING TO POPULATION AND CONSUMPTION

	1950	1968	Est. for 1980	Inter. Proj. for 2000
POPULATION (millions)	152	202	235	320
TOTAL POWER CAPACITY (millions of kilowatts)	85	290	600	1,352
KW CAPACITY / PERSON	0.6	1.4	2-½	~ 4-¼
POWER CONSUMED PER PERSON PER YEAR (kilowatt-hours)	2,000	6,500	11,500	~ 25,000
TOTAL CONSUMPTION (kilowatt-hours)	325 billion	1.3 trillion	2.7 trillion	~ 8 trillion
NUCLEAR POWER CAPACITY % OF TOTAL	0	< 1%	25%	~ 69%

power demands. A recent report [5] to the Federal Power Commission indicates that between now and 1990 the power industry in these eleven states must build about four times as much electrical generating capacity as the industry has provided thus far in its 80 year history. In other words, about four times the existing capacity must be built in one-fourth the time to meet the projected public needs. Based on current prices, these tremendous undertakings will involve an investment of something like $50 billion for generation, transmission, and distribution facilities.

This same report concludes that nuclear power will account for about 60 percent of the total generation in the Northeast by 1980 and more than 80 percent by 1990. Reasons for the choice of nuclear power, particularly in the New England-New York areas, are the low fuel cost, the low fuel transportation cost, and the virtual absence of atmospheric pollutants from nuclear fuels.

RADIOACTIVITY

Nuclear reactor technology has been under development in the United States for more than 25 years. During this time, the knowledge necessary to protect public health and

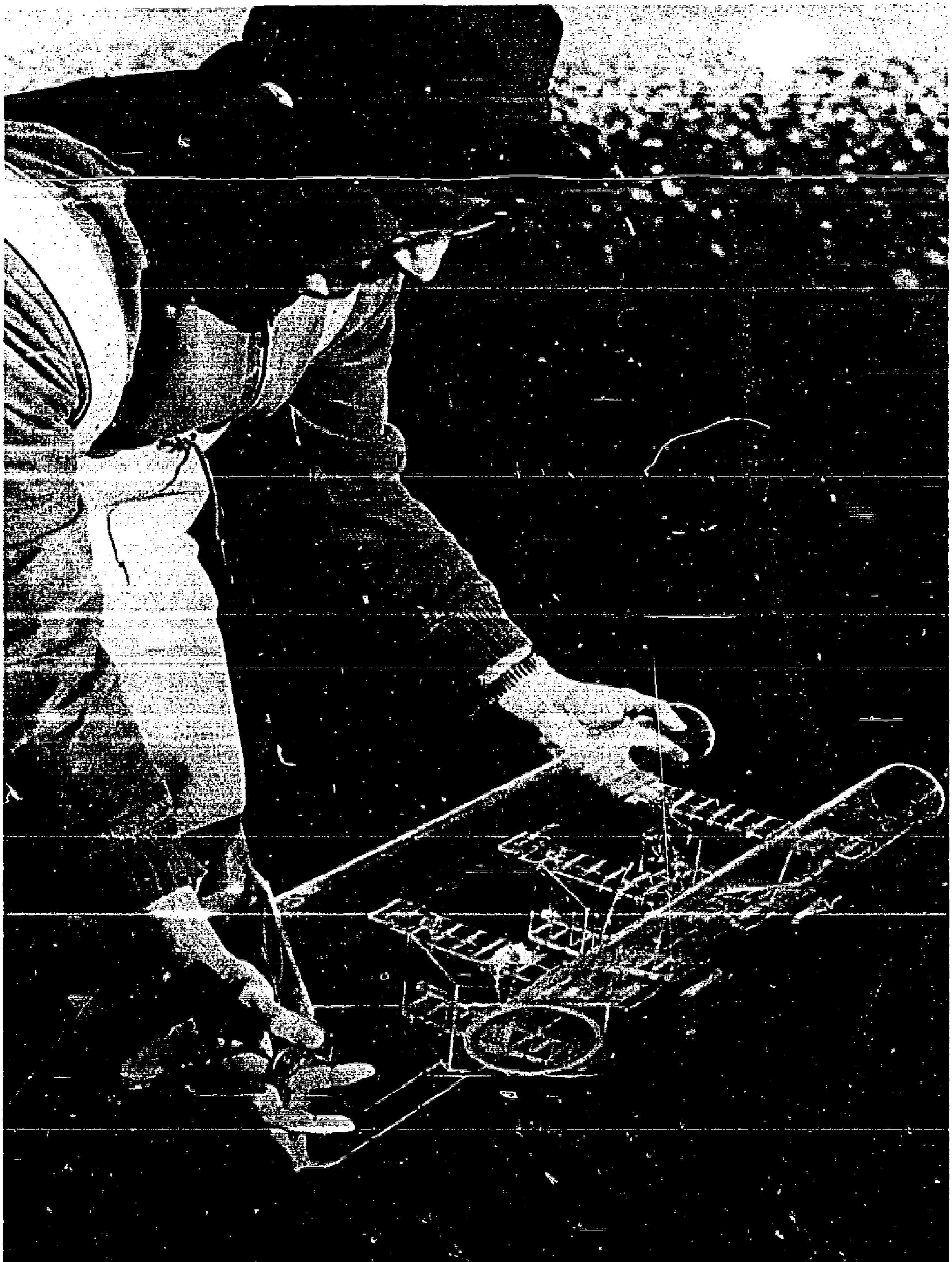
[5] *Electric Power in the Northeast 1970–1980*, A Report to the Federal Power Commission, prepared by the Northeast Regional Advisory Committee, December 2, 1968.

safety has advanced along with the technology itself. Protection of public health and safety in the design, construction and operation of reactors is a statutory responsibility of the AEC under the Atomic Energy Act of 1954 and the Commission regards this as an overriding consideration in all its activities including the licensing and regulation of nuclear power reactors. In carrying out this responsibility, the AEC devotes special attention to assuring that radioactive wastes produced at nuclear power reactors and other facilities are carefully managed and that releases of radioactivity into the environment are within Governmental regulations.

The management of radioactive waste material in the growing nuclear energy industry can be classified under two general categories. The first is the treatment and disposal of materials with low levels of radioactivity. These materials are the low activity gaseous, liquid and solid wastes produced by reactors and other nuclear facilities such as fuel fabrication plants. The second category involves the treatment and permanent storage of much smaller volumes of wastes with high levels of radioactivity. These high level wastes are by-products from the reprocessing of used fuel elements from nuclear reactors. It is important to understand the difference between the low level reactor wastes with a low hazard potential and the high level fuel reprocessing wastes with a higher hazard potential. Unfortunately, these two types of radioactive wastes are still considered a single entity by many people.

Neither the reprocessing of used fuel nor the disposal of high level wastes is conducted at the sites of the nuclear power generating stations. After the used fuel is removed from the reactor, it is securely packaged and shipped to the reprocessing plant. After reprocessing, the high level wastes are concentrated and safely stored in tanks under controlled conditions at the site of the reprocessing plant. Only a few reprocessing plants will be required within the next decade to handle the used fuel from civilian nuclear power plants. As with the power reactors, the AEC carefully regulates the operation of such plants.

More than 20 years of experience has shown that underground tank storage is a safe and practical means of interim



A plankton trap is placed in a river as part of a long-range study of radionuclide uptake by aquatic organisms.

handling of high level wastes. Tank storage, however, does not provide a long term solution to the problem. Accordingly, using technology developed by the AEC, these liquid wastes are to be further concentrated and changed into solid form. These solids will then be transferred to a Federal site, such as an abandoned salt mine, for final storage. These salt mines have a long history of geologic stability, are impervious to water, and are not associated with usable ground water resources. This procedure will provide assurance that these high level wastes are permanently isolated from man's environment.

Technology developed for the treatment and storage of radioactive wastes produced at presently operating power reactors is considered more than adequate for the expanding industry during the next decade. These treatment systems include short term storage of liquid wastes, evaporation, demineralization, filtration of liquids and gases, and compression of solid wastes. They also include chemical treatments to concentrate radioactive materials, and immobilization of radioactive solids and liquids in concrete or other materials.[6]

Operating experience in licensed power reactors shows that levels of radioactivity in effluents have generally been less than a few percent of authorized release limits. Environmental monitoring programs to measure radioactivity are carried out by licensees, some of the States, the Bureau of Radiological Health of the U.S. Public Health Service, and the AEC. The quantities of radioactivity released are so small that it has been difficult to measure any increase in radioactivity above background levels in rivers and streams which can be attributed to effluents from nearby nuclear power reactors.

Basis for Release Limits

AEC regulations on radiation protection are based principally on the radiation protection guides recommended by the Federal Radiation Council (FRC) and approved by the President for guidance of all Federal agencies. In 1959 Congress established the FRC to ". . . advise the President with respect to radiation matters, directly or indirectly affecting health, including guidance for all Federal agencies

[6] For more information see *Radioactive Wastes*, another booklet in this series.

in the formulation of radiation protection standards and in the establishment and execution of programs of cooperation with States . . ." After the recommendations of the FRC are approved by the President, they are published in the Federal Register for guidance of Federal agencies.

The recommendations of the FRC are developed with the assistance of appropriate Federal agencies, the National Academy of Sciences and the National Council on Radiation Protection and Measurement (NCRP). In addition to their own expertise, the members of these groups seek the advice of other highly qualified scientists and researchers with specialized knowledge of the many factors that determine the effects of radioactivity on man.[7] The results of the extensive experimental programs on the behavior and effect of radioactive material in the environment and in living tissue are also carefully considered in developing the FRC guidelines. The standards set by the FRC are reviewed as new research information becomes available or as new problems arise to determine whether changes in these guidelines are needed.

AEC limits human exposure by establishing release limits. A concentration limit is set up for each radionuclide or specific type of radioactive material. These are derived such that an individual who consumes water at the concentration limit in his drinking (and cooking) water (about 2 quarts per day) or inhales air at the concentration limit for his lifetime is not likely to be exposed in excess of the dose limits.

A few words about reconcentration of radioisotopes are in order since considerable misunderstanding has developed in this area. Reconcentration refers to the fact that aquatic and marine forms selectively remove certain elements from the water or from their food. These elements (in various chemical forms) may be incorporated into the body or body fluids of the organism. Consequently the organism may have a higher concentration of certain elements than the concentration found in water. If a radioisotope of one of these elements is biologically available it may be taken up along with its stable form and likewise be concentrated in the organism.

Reconcentration of radionuclides by aquatic and marine

[7] See *Your Body and Radiation* and *Genetic Effects of Radiation*, other booklets in this series.

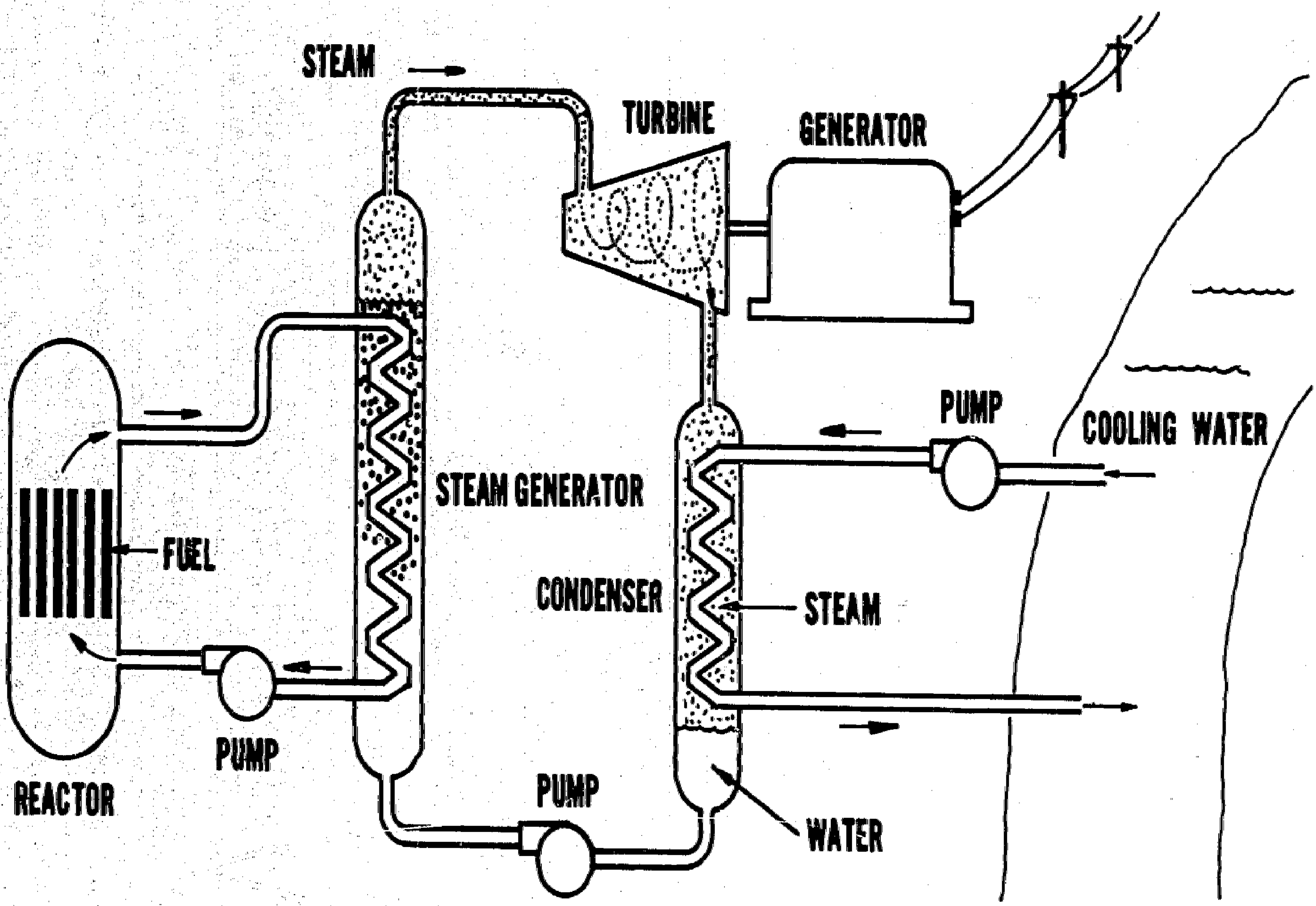
food organisms is taken into consideration in AEC regulations. These regulations provide that in addition to limits on concentrations, the AEC may further limit quantities of radioactivity released from a reactor if it appears that the daily intake of radioactive materials from air, water or food by a suitable sample of an exposed population group from all sources, including multiple reactor sites, would otherwise exceed FRC radiation protection guides. In practice, releases of radioactivity from nuclear power plants have been so low that the AEC has not found it necessary to implement this provision of the regulation. Operating experience to date has shown that exposures to the population in the vicinity of nuclear power plants from radioactivity in plant effluents are only a small fraction of radiation protection guides.

THERMAL EFFECTS

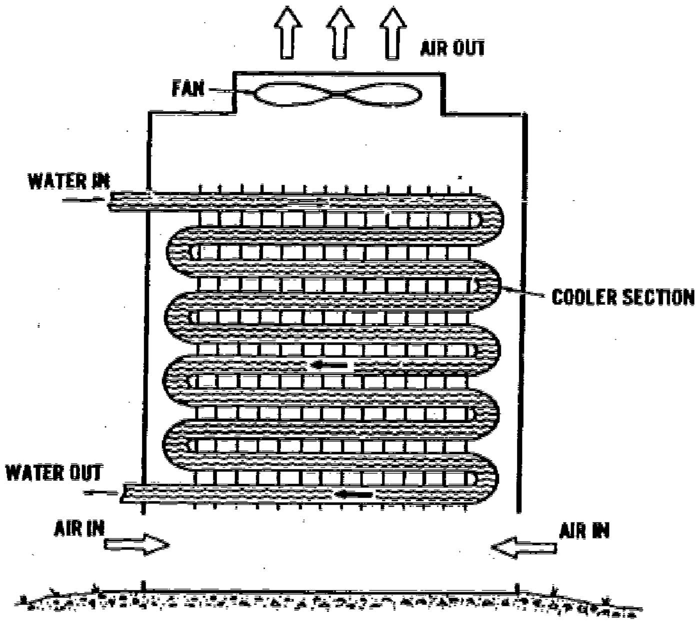
All steam-electric generating plants must release heat to the environment as an inevitable consequence of producing useful electricity. Heat from the combustion of fossil fuel in a boiler or from the fission of nuclear fuel in a reactor is used to produce high temperature and pressure steam which in turn drives a turbine connected to a generator. When the thermal energy in the steam has been converted to mechanical energy in the turbine, the "spent" steam is converted back into water in a condenser.

Condensation is accomplished by passing large amounts of cooling water through the condenser. In the least costly and most widely used method, the cooling water is taken directly from nearby rivers, lakes, estuaries, or the ocean. The cooling water is heated 10 to 30 degrees F.—depending on plant design and operation—and then usually returned to the same source. Thermal effects is a term which is used to describe the impact that the heated water may have on the source body of water.

The thermal effects may be detrimental, beneficial or insignificant, depending on many factors such as the manner in which the heated water is returned to the source water, the amount of source water available, the ecology of the source water and its desired use. The addition of the heated water from the plant condenser to the source body of water



Cooling water flow in a nuclear power plant.



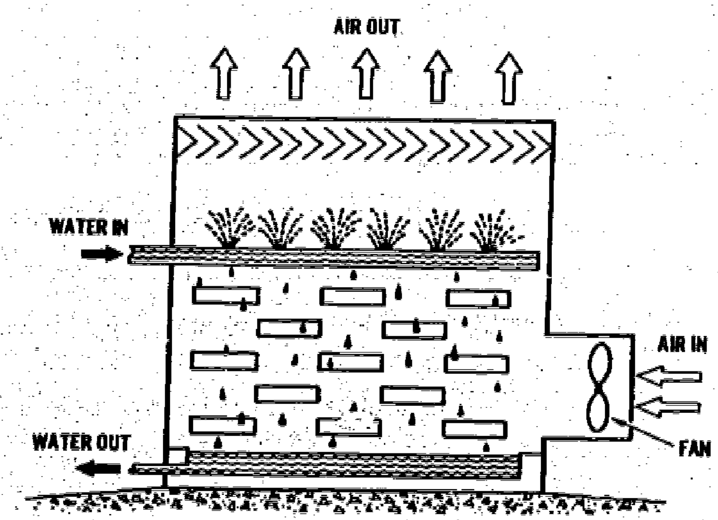
A dry cooling tower system in which the flow of air is provided by mechanical means.

does raise its temperature and this increased temperature can affect fish and other aquatic life. However, these effects can be localized or minimized.

In some situations, cooling methods other than the once-through method described above may be employed. Artificial ponds can be constructed to provide a source of water for circulation through the condensers. Cooling towers—either of the wet or dry type—can be used in other instances. Combinations of cooling methods can also be used effectively in many situations.

In wet cooling tower systems, the cooling water is brought in direct contact with a flow of air and the heat is dissipated principally by evaporation. The flow of air through the cooling tower can be provided by either mechanical means or

A wet cooling tower system in which the flow of air is provided by mechanical means.



natural draft, and make-up water must be added to replace evaporative losses.

In dry cooling tower systems the cooling water is carried through pipes over which air is passed and the heat is dissipated by conduction and convection rather than by evaporation. Because of the larger surface area required for heat transfer and the larger volume of air that must be circulated, dry cooling towers are substantially more expensive than wet cooling towers and hence seldom used.

It is important to emphasize that although these alternatives may offer relief from a potential thermal effects problem, their use can involve other environmental effects and economic penalties. Whatever method of cooling is chosen, the waste heat—from both fossil and nuclear plants—still must eventually be dissipated into the environment.

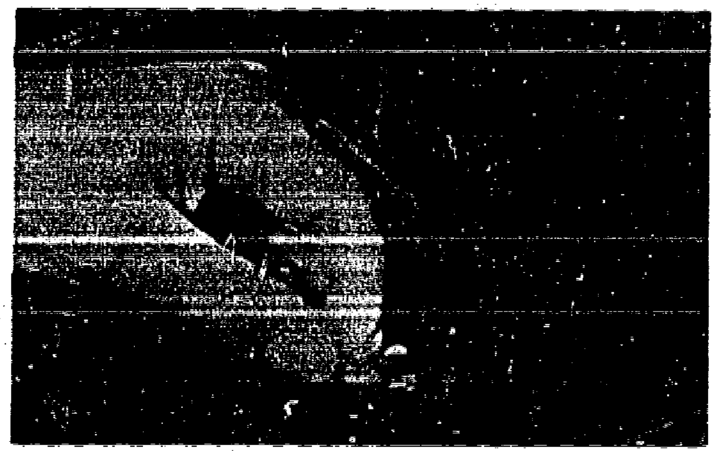
The light water power reactors currently being marketed operate at a lower efficiency and therefore reject more heat than the most modern of today's fossil fuel plants of the same generating capacity. For this reason and because about 10 percent of the heat from fossil fuel plants is discharged directly into the atmosphere through the stack, modern fossil fuel plants currently discharge approximately one-third less waste heat to cooling water than do nuclear plants. With the advanced reactors now under development, however, the difference in the amounts of heat released to the cooling water by nuclear and fossil plants will be greatly reduced.

Because so much of today's power comes from conventional fossil fuel plants, they are the major contributors of waste heat to the environment today. In 1968, nuclear power contributed only about one percent of the waste heat. However, at estimated rates of growth, 30 percent of the heat wasted by steam generating plants in 1980 will come from nuclear plants. By 1995, the contributions from both sources are expected to be about equal.

Government Sponsored Research

Considerable thermal effects research has been conducted and more is under way or planned. As discussed in Section V of this report, the AEC has been studying the effects of reactor heat added to the Columbia River since 1946. In Fiscal Year 1969, the AEC spent over $600,000 on the study of thermal effects; this was a substantial portion of the Federal effort in this area. In view of the large number of nuclear power plants being built,[8] the AEC plans to increase the number of studies in coming years. Some idea of the scope of the AEC program is given by the following.

The AEC's Pacific Northwest Laboratory, operated by Battelle Memorial Institute, has completed a mathematical simulation of temperatures in the Illinois and Deerfield Rivers below the Dresden and Yankee nuclear power plants in Illinois and Massachusetts respectively, and also in the Upper Mississippi River Basin. This research indicates that large streams can accept and then reject considerably greater quantities of heat without exceeding water quality

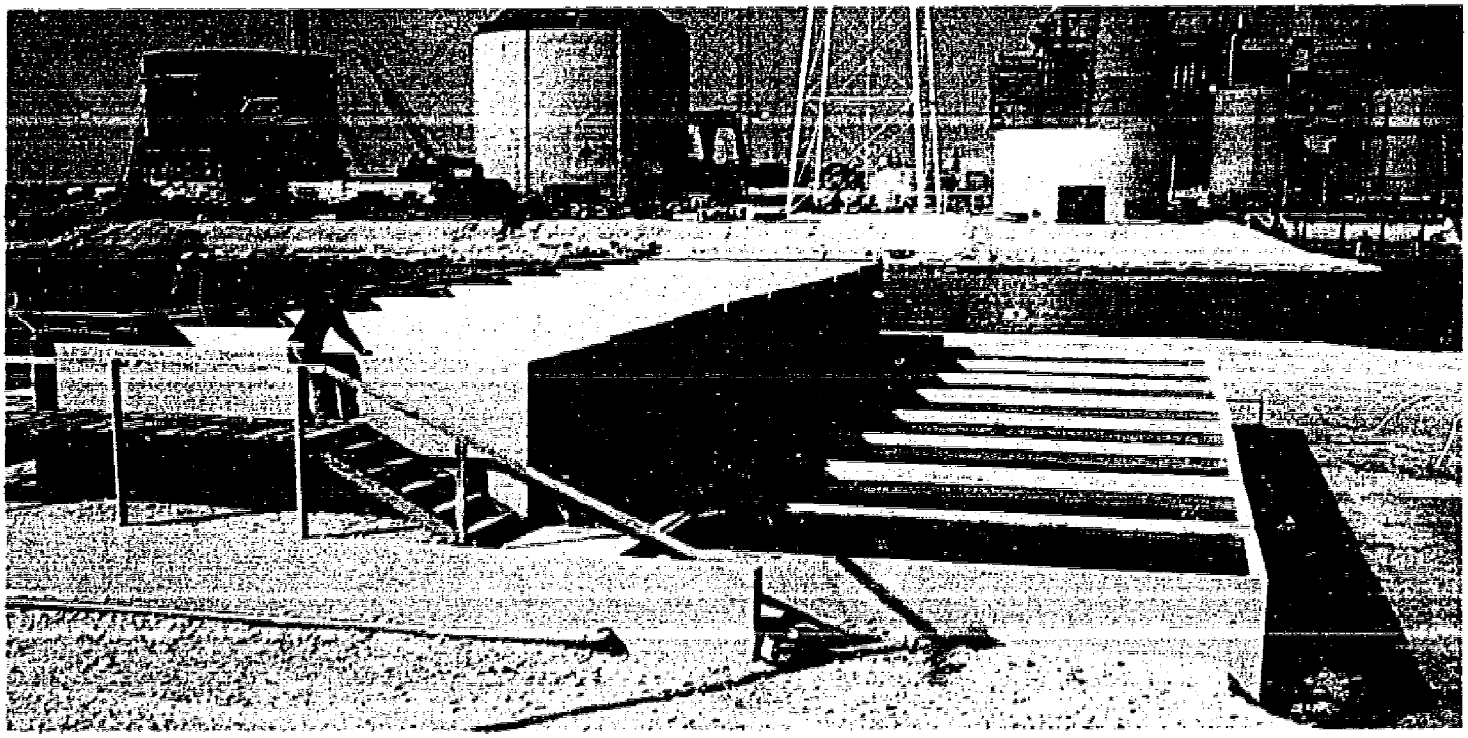


Shrimp raised in warm water at the Turkey Point research facility, operated by the University of Miami.

standards than would be indicated by routine calculations using average river flows and plant cooling requirements. This mathematical simulation technique is now being used to determine the impact of power growth, as predicted by the Federal Power Commission, on major river systems.

The AEC is also supporting research at the Chesapeake Bay Institute of Johns Hopkins University to determine the distribution of added temperature from power plant discharges into coastal and estuarine waters. The ability to predict temperature distributions is being developed through model studies. These are to be followed by field investigations in the summer of 1969 in the Potomac River estuary adjacent to the Morgantown, Maryland conventional power station.

[8] See *Nuclear Power Plants and Nuclear Reactors*, other booklets in this series. Also see *Nuclear Reactors Built, Being Built, or Planned in the United States* listed in the Suggested References on page 30.



Outdoor facility for shrimp and pompano consists of 16 concrete tanks of seawater. In the background is the Turkey Point nuclear reactor under construction.

The AEC is supporting the University of Miami's ecological study of the South Biscayne Bay in the vicinity of Turkey Point, Florida. The research is directed at determining the effects of heated power plant effluents on marine organisms, especially the changes in the ecological community structure that may occur in time and space as a result of increased water temperatures.

Several Federal agencies other than the AEC are also conducting extensive research on thermal effects. Some examples of their efforts are found in a recent Federal Power Commission [9] report. In addition, the Smithsonian Institution's Science Information Exchange lists 70 Federally supported thermal effects research projects.

The Federal Water Pollution Control Administration (FWPCA) of the Department of Interior has established a National Water Quality Laboratory near Duluth, Minnesota. A current major effort of this Laboratory is the determination of the effects of heated water on fish and aquatic

[9] *Problems in Disposal of Waste Heat from Steam-Electric Plants*, Federal Power Commission, Bureau of Power, 1969.

life. The FWPCA has also instituted a national thermal effects research program at its Pacific Northwest Water Laboratory at Corvallis, Oregon. The objective of this program is to coordinate various thermal effects studies.

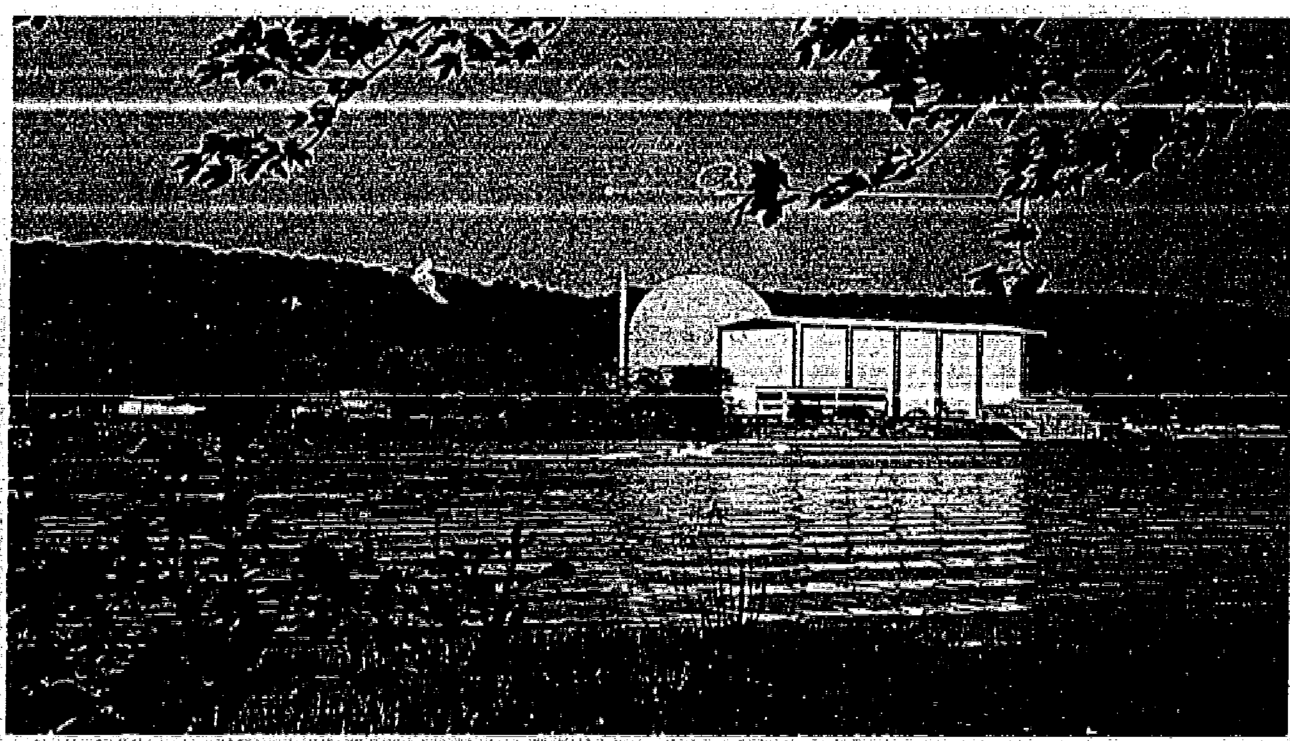
At the present time, the FWPCA, in cooperation with the Tennessee Valley Authority, is planning a research project at its Browns Ferry, Alabama, nuclear power plant. Preliminary planning involves the construction of eight identical channels, each 14 feet wide, 390 feet long, and varying in depth from one to four feet. The channels will contain flowing water at various temperatures. The purpose of the project will be to obtain information on the effects of elevated temperatures on reproduction and rate of growth of several species of warm-water fish and of fish-food organisms.

The Sandy Hook Marine Laboratory (New Jersey) of the Bureau of Sport Fisheries and Wildlife, U.S. Department of Interior, is investigating the ability of various marine fish and invertebrates to adapt to temperature changes due to thermal discharges from power generating stations.

Utility Industry Sponsored Research

The electric utilities are also sponsoring thermal effects

The Connecticut Yankee Atomic Power Plant at Haddam Neck, Connecticut.



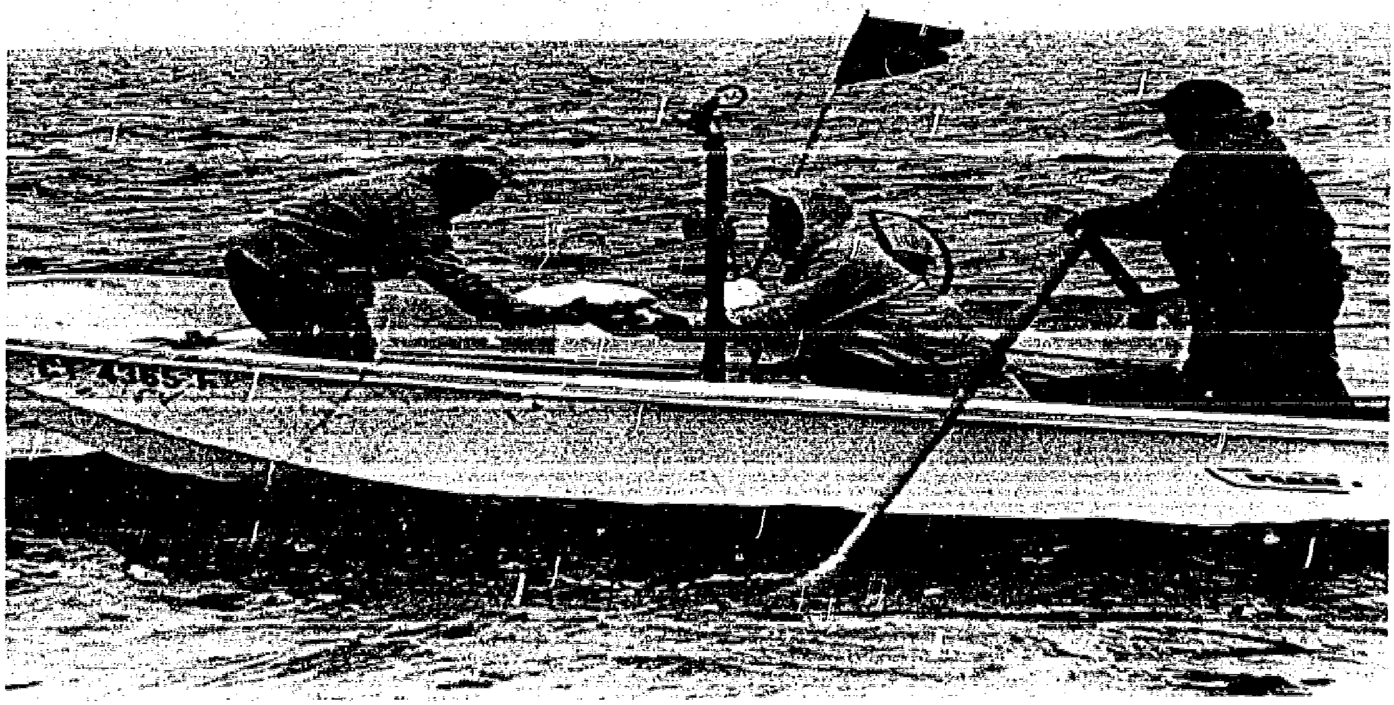
studies and research. Typical thermal effects programs for power plants being built or planned involve tidal, lake or river current measurements; hydraulic model studies; predictions of the temperature distributions due to discharge of heated water; pre-operational temperature measurements, using a variety of techniques; and ecological studies, one or two years in duration, to obtain baseline data in the vicinity of the plant site. Furthermore, the plants will perform post-operational studies to determine what changes are occurring or have occurred in the aquatic environment.

The scope and depth of thermal effects research conducted for individual nuclear power stations have increased considerably in recent years. A prime example of such research is the comprehensive study of the fish life, ecology, and hydrology of the lower Connecticut River in the vicinity of Connecticut Yankee's nuclear power plant at Haddam Neck. The study, being carried out by a group of independent scientists through financing made available by Connecticut Yankee, was initiated in the fall of 1964. Research funds committed to date have totaled more than $750,000.

The study covers six major areas of investigation: (1) hydrology, (2) studies of organisms on the river bottom, (3) fish studies, including both resident and migrating (shad) populations, (4) bacteriology, microbiology and algae studies, (5) radiological surveys and (6) thermal studies. The thermal study work has included temperature distribution predictions and measurements using a variety of techniques such as flow measurements and airborne infrared temperature surveys.

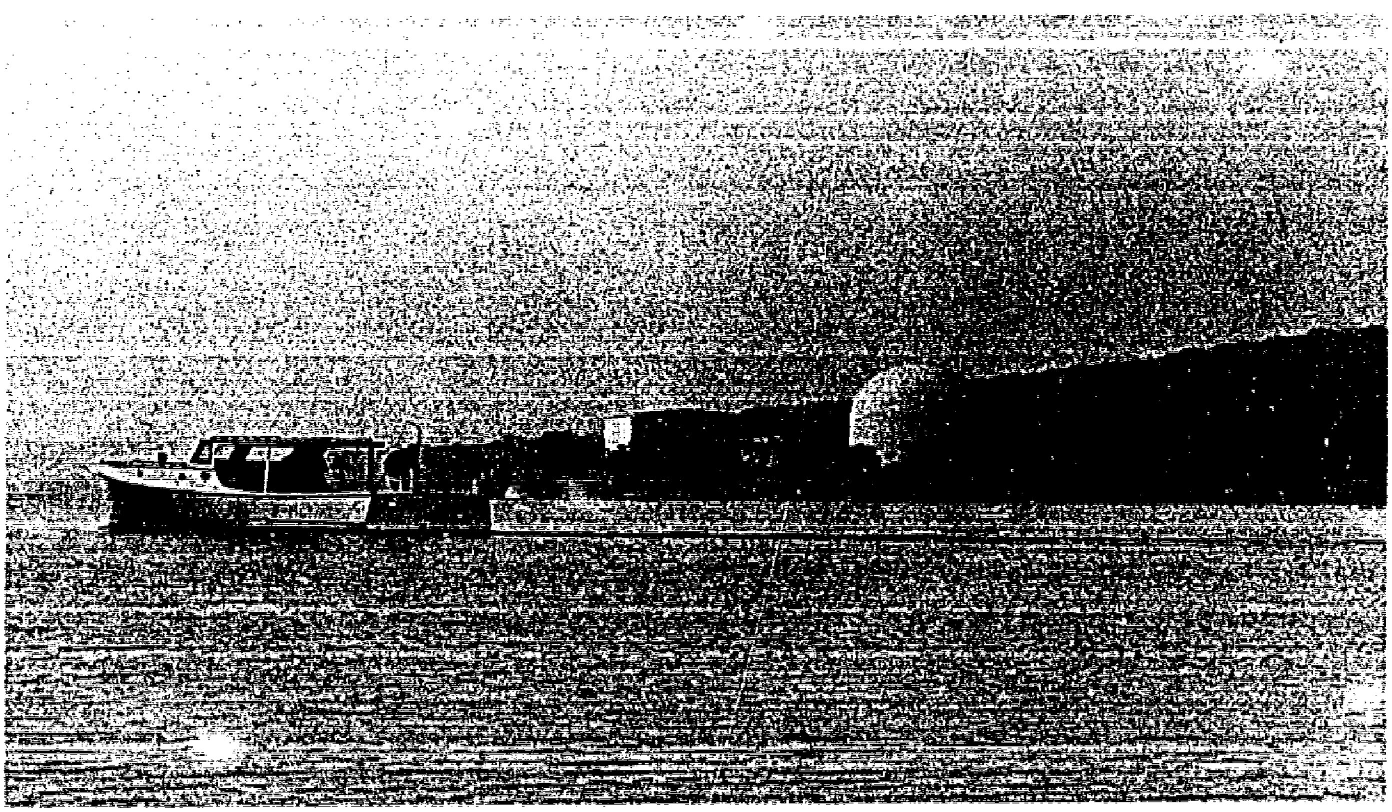
The study is an excellent example of a cooperative program between industry, the academic and scientific communities, and state and Federal agencies. This cooperation is clearly evidenced with the work being done by the Connecticut Board of Fisheries and Game, The Connecticut Water Resources Commission, The Connecticut State Department of Health, The Marine Research Laboratory of the University of Connecticut and the United States Geological Survey as part of the study effort.

Broad guidance for the conduct of the study is provided by an Advisory Board, consisting of five marine biologists, all of whom are recognized authorities in their fields. The



Connecticut River shad (center of photo) about to be tagged by men operating gill nets.

Temperature readings of the warm-water plume taken downstream from the Connecticut Yankee Plant (visible in background).



Advisory Board meets twice a year to evaluate the study's progress and to provide overall direction of the various aspects as it moves forward.

The 567,000 kilowatt nuclear plant started up in July 1967. It achieved initial full-power operation at 462,000 kilowatts in January 1968. The plant obtained its present full-power level in March of 1969. The environmental study is planned to continue at least until 1973.

The shad tagging program, now in its fourth year, has shown that the pattern of upstream migration is substantially the same as that before the plant went into operation. The radiological survey of river water, fish, shell fish, plankton, and bottom sediment has shown only a negligible increase in radioactivity since the plant has been in operation. The Connecticut River Study Staff and cooperating agencies as yet have found no significant change in the ecology of the Connecticut River resulting from the discharge of heated water from the Connecticut Yankee Atomic Power Plant after more than two and one half years of operation.

Commonwealth Edison Company, in cooperation with Northwestern University and the Illinois State Department of Conservation, made studies of the effects of the discharge of cooling water from a fossil fueled plant at Waukegan on Lake Michigan. This plant was selected because it has been operating for 40 years and any possible long time deleterious effects of thermal discharge would be apparent. A similar study was made at the same time at an undisturbed site four miles north of the Waukegan Station near Zion, Illinois. Similarities in aquatic environments were observed at both locations. The bottom-living organisms important in food chains of valuable fish have not been killed by the warm effluent of the Waukegan plant. Plankton counts do not show any definite changes due to the plant's operation. The sport fish in the area have not suffered any ill effects either. The extended period of higher temperature has had only a slight effect on the chemistry of the lake water and has not significantly changed the dissolved oxygen concentration. In summary, it appears that no significant effect on the total near shore environment can be attributed to the discharge of cooling water from the Waukegan plant.[10]

[10] No Notable Change in Lake Due to Station Discharge, L. P. Baer and W. O. Pipes, *Electrical World Features*, February 10, 1969.

Detailed biological surveys have been made at all but one of TVA's steam plants. No significant effects on aquatic life have been found except at the Paradise plant on the small Green River in Kentucky. Here, observed effects on fish-food organisms indicated more control of maximum stream temperatures to be desirable. Cooling towers have been built to alleviate the problem.[11]

At Consolidated Edison's Indian Point Nuclear Power Station on the Hudson River where a 265,000 kw unit started up in 1962, studies have detected no adverse effects upon the river's plant and animal life. In fact, the studies indicated that perhaps there was a greater variety of animals present in the effluent canal, possibly because the canal provides a more sheltered and varied environment than the mainstream of the river. At Southern California Edison's Nuclear Power Plant at San Onofre, where a 430,000 kw unit started up in 1967, a detailed analysis of 18 surveys (July 1963 to December 1968) gave no indication that the community structure in the San Onofre sand and cobble reef ecosystems had been altered by thermal discharges.

The following studies are being made for the Pilgrim Nuclear Power Station, a 625,000 kilowatt unit being built for Boston Edison Company near Plymouth, Mass.: (1) sea current measurements, (2) topographic scale model studies (by Alden Research Laboratories), (3) hydraulic thermal model studies (by MIT), (4) thermal discharge predictions (by Chesapeake Bay Institute), (5) pre-operational temperature distribution measurements, (6) pre-operational studies of fish distributions and commercial catches, and (7) prediction of the ecological effects of heated water discharge (Woods Hole Oceanographic Institute). In addition, the Boston Edison Co. has a 4 year survey contract with the Commonwealth of Massachusetts to monitor marine life and temperature distributions.

The Edison Electric Institute, with the support of investor owned utilities, recently compiled and published a list of environmental studies on water problems. The list contains 266 studies either completed or under way and 41 pro-

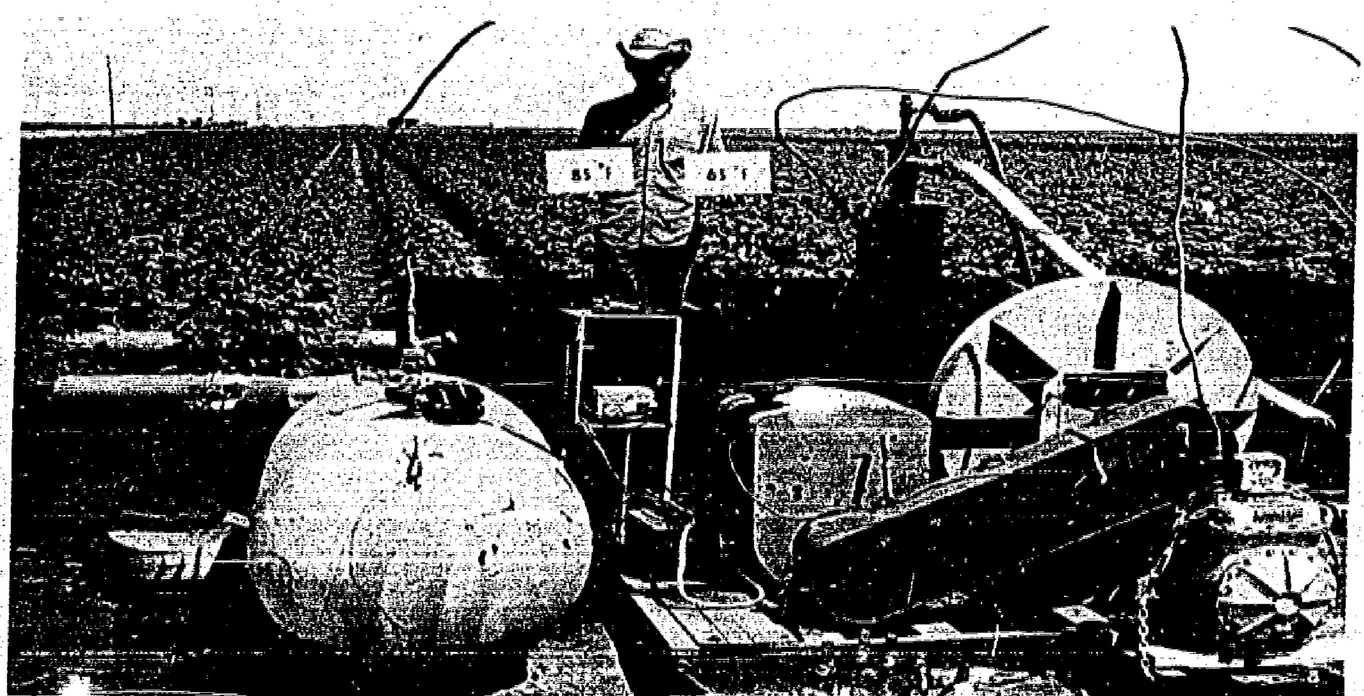
[11] *Effects of Heated Discharges on the Aquatic Environment: The TVA Experience*, M. A. Churchill and T. A. Wojtalik, Presented to the American Power Conference, Chicago, Illinois, April 22–24, 1969.

posed studies. With few exceptions these studies concerned the characteristics of particular plant sites.

One notable exception is a study in progress by Johns Hopkins University for the Edison Electric Institute. This study, entitled "Cooling Water Studies," has been under way since 1962. The objectives in the first phase of this study were: to summarize existing knowledge; to apply this knowledge in the development of useful analytical techniques; to determine what additional information will be needed; and to suggest what the industry might undertake to acquire needed information. Two papers, "Water Temperature and Aquatic Life" and "Heat Exchange in the Environment," were published as a part of Phase I. This research has shown among other things, that the ability of a body of water to cool is greater at low wind speeds than had been anticipated.

Phase II of the study is now under way. Eleven sites have been selected, instrumented and are being observed during a wide range of plant discharge conditions. The sites offer a variety of hydrologic conditions. Four are located on rivers, two on deep stratified lakes, two on shallow lakes or cooling ponds, and three on tidal bodies.

An experiment in Texas in which heated water (85° F) is used to irrigate a cotton crop. The control crop is irrigated with unheated water (65° F).



Beneficial Uses

Although a considerable amount of thermal effects research has been conducted, more attention should be given to beneficial uses of heated water. For example, it has been proposed that heated water be used to irrigate crops and to warm the soil, thereby possibly extending the growing season or protecting crops from freezing. Aquaculture also is a distinct possibility since productivity of commercial species (such as catfish) can probably be greatly increased, particularly in winter months.

Use of byproduct heat to delay freezing and thereby to extend the shipping season in northern waterways has also been suggested. Obviously, more can be done along these lines. Heated water is an energy source, which suggests that ingenuity can find beneficial uses for this energy.

Another alternative exists in the sea where water is plentiful and where the temperature structure in many areas is especially promising for beneficial modification by thermal discharges. Oceanographers have asked if there is some way to use the excess energy from a steam power plant to induce upwelling in the ocean and thus enhance the biological productivity. The ocean is relatively stable, with warm, less dense water overlying cold denser water. Separating the two is a layer, usually at a depth of 300 to 2,200 feet, where there is a sharp temperature change (the thermocline). In the summer, particularly in mid latitudes where seasonal temperature variation is greatest, a thermocline develops much nearer the surface. Water below this thermocline is not only colder than surface water, but also much richer in nutrients.

Growing plants are sparse or absent in the deeper water, because there is insufficient light. Above the thermocline light is usually abundant, but nutrients such as nitrate and phosphate are in short supply. If the nutrients of the colder, deeper water could be transported upward into the warmer upper layers, biological productivity could be increased. A vastly more productive and valuable fishery might develop in the vicinity of the nutrient-rich water.

On the other hand, changes in the temperature regime may favor growth of undesirable species, and organisms commonly used by man may be crowded out. Perhaps both views are correct, depending on geographical location. In our present knowledge of the probable response of marine ecosystems to artificially induced upwelling and limited heating, feasibility studies seem worth pursuing. A concerted attack on this problem will be needed if a productive solution is to be found. The potential of the ocean to benefit from the intelligent use of waste heat makes a concerted effort highly desirable.[12]

AEC OPERATING EXPERIENCE

During the last 25 years the AEC has gained considerable knowledge from reactor operations at its Hanford (Washington) and Savannah River (South Carolina) sites. In addition, the AEC has had an Environmental Sciences Branch (ESB) for more than 12 years, supporting the work of many of the Nation's leading ecologists. During this time, about $70 million has been expended in ESB programs with over $9 million included in the Fiscal Year 1969 budget and almost $10 million programmed for Fiscal Year 1970.

The Manhattan Project—the Nation's effort during World War II to develop the atomic bomb—included the construction of the large Hanford reactor complex on the Columbia River near Richland, Washington. Unlike commercial power reactors, the Hanford reactors were designed with a "single pass" cooling system in which river water was passed directly through the reactor and returned to the river. Further, since the Hanford reactors were for the production of plutonium rather than power, all of the heat from the reactors was discharged to the environment. For these reasons, these first Hanford reactors released more heat and radioactivity to the environment than the present commercial nuclear power plants.

Even during the earlier days of the Manhattan Project the possibility of environmental effects of the radioactivity and heat was recognized, and in 1943 the Applied Fisheries Laboratory of the University of Washington was brought into the plutonium project during construction of the Hanford plant. Since that time the Laboratory with AEC sup-

[12] See *The Atom and the Ocean*, another booklet in this series.

port has been continuously studying effects of reactor effluent on salmon, oysters, and other life forms in the river.

The Columbia River is a large, cold, clean river which supports runs of salmon, steelhead, and shad. There were six reactors operating during 1944–1955, and eight from 1955–1964. In 1964, the river had nine nuclear reactors in a short stretch through the Hanford reservation, but the number operating has since decreased to three as a result of declining defense needs. It is worth noting how salmon, which require cold water, have responded to the reactor operation.

A recent report summarizes some of the results of work [13] which has been under way for about 20 years at the Hanford site. During the period of the study, all but 44 miles of the salmon spawning area on the Columbia has been inundated by water backed up by a series of dams. The only spawning areas left are from Richland up to the Priest Rapids Dam. Much of this fast water lies in the Hanford Reservation in the vicinity of the reactors. The heat discharged by the reactors has had no apparent effects upon salmon eggs or fry, probably because the salmon spawn while the natural river temperature is low (mid-October through November).

The question of whether the heated water from the reactors interferes with the passage of fish is also being studied to determine if the fish trying to migrate up to tributaries of the Columbia above Hanford will be prevented from passing. The Bureau of Commercial Fisheries and the Battelle Northwest scientists have been observing the movement of adult salmon tagged with sonic emitters. Results indicate the fish avoid the warmer water on the reactor side of the river, but the important point is that their progress past the reactor site is not impeded. The fish migrate along the same shoreline above the reactor discharge so factors such as current velocities may also be important in determining their path.

Perhaps the best evidence of the absence of any harmful effects from the reactors on Columbia River salmon is the increase in nesting sites on the Hanford reservation.

[13] *Biological Effects of Hanford Heat on Columbia River Fishes—A Review*, R. Nakatani, Presented to the Isaac Walton League, Portland, Oregon, February 17, 1968.

"The numbers of salmon nests observed has increased from about 300 prior to 1950 to a record number (sic.) of over 1,700 in 1965, 3,100 in 1966, and to a 21 year record high of 3,300 in 1967. This increase (perhaps due in part to the partial barrier created by the Priest Rapids Dam just upstream) has occurred during a period of years when the runs of fall Chinook salmon to other parts of the river system (i.e., the Snake River) have declined appreciably . . . The ultimate fate of Hanford stock of Chinooks and steelhead is . . . dependent upon the proposed construction of Ben Franklin Dam above Richland that would inundate and destroy the Hanford spawning area." [14]

To summarize, the Columbia River system with its large reactor complex has been studied since the Hanford plant was first being built in 1943. Scientists from Battelle Northwest Laboratories, the University of Washington, the Bureau of Commercial Fisheries, the U.S. Geological Survey and Oregon State University are presently engaged in this

[14] Ibid.

Chinook salmon in the University of Washington's campus pond. Researchers are trying to discover why irradiated salmon return to spawn in greater numbers than do nonirradiated salmon.

A water sampler at a large pond fed by cooling water from a production reactor at the Savannah River facility.

research. There are hundreds of published reports on phases of the work. A book incorporating many of the results is being funded by the AEC, and should be ready for publication in 1970.[15] Monitoring of food organisms (salmon, whitefish, oysters, etc.) is being routinely carried out by state health agencies of Oregon and Washington and by Battelle Northwest. No adverse effects have been detected on salmon populations in the vicinity of the Hanford reservation as a result of the releases of radioactivity and heat into the Columbia River.

Considerable experience has also been gained in the operation of the AEC facilities at Savannah River, South Carolina. Par Pond, a small lake on the site, receives reactor effluent wastes from the Savannah River reactors. The basic ecology of this lake has been studied intensively. All of the components of the living system have been examined, and the lake appears no different from nearby lakes. The number of species of aquatic organisms and the relative sizes of their populations are not different from these other

[15] *Bioenvironmental Studies of the Columbia River Estuary and Adjacent Ocean Region,* see Suggested References on page 30.

lakes, which indicates that the system is a healthy one. This is an important measurement in evaluating the health of an aquatic community of plants and animals. As these communities are probably more sensitive to environmental changes than are their individual components, the conclusion is that the Savannah River plant operations have not affected the community adversely.

The Savannah River facility uses heavy water moderated reactors. Neutron captures in heavy water can produce the radioisotope tritium. Also, reprocessing of fuel at the Savannah River facility leads to the emission of tritium. Thus, levels of tritium in the Savannah River are higher than in most areas, averaging about 0.3 to 0.4 percent of the MPC.[10] Evidence here indicates there is little if any biological concentration of tritium. That is to say, the body water of animals drinking Savannah River water had about the same concentration of tritium as did the river water.

The Hanford and Savannah River experience can be applied to evaluation of the environmental effects of commercial nuclear power stations. It is very significant and encouraging that the releases of heat and radioactivity at the two locations have not unduly disturbed the surrounding environment.

CONCLUSION

The rapidly increasing demands for electrical power in this country must be met on an economical and reliable basis in order to sustain economic growth and continue to raise the American standard of living. The only practical means of producing power in the large amounts required is to build more steam electric power plants—both fossil fired and nuclear. These plants will inevitably have an impact on the environment. The challenge facing us is to minimize the effects and to achieve—within prevailing economic and technological limitations—our twin goals of low cost, reliable power and preservation of the quality of our environment.

With its deep concern for both protection of the environment and meeting the Nation's massive energy needs, the Commission is convinced that nuclear power best meets

[10] *Sources of Tritium and Its Behavior Upon Release to the Environment*, see Suggested References on page 30.

Technicians cruise the swampland bordering the Savannah River facility to assure that the flow of warm water from the reactors does not exceed limitations. Fish populations in the area show no detrimental effects as a result of facility operations.

these twin objectives. The Joint Congressional Committee on Atomic Energy supported this conviction in its Fiscal Year 1970 Authorization Report on AEC Appropriations:

> "The Committee is equally convinced that those members of the general public with genuine questions and concerns will come to realize that, in terms of their relative impact on the environment, nuclear plants in many respects are the least offensive of the various thermal generating units. Most importantly, these plants emit none of the combustion products released to the atmosphere each day by a fossil-fueled plant; they can, therefore, contribute materially to the fight for clean air."

This is not to suggest that problems don't exist or that there are easy answers to meeting these twin goals. The issues are not going to be resolved easily, and substantial understanding on the part of all parties will be essential. Provided that everyone seeks constructive solutions, there is indeed a basis for optimism that the many benefits of nuclear power can be realized without unduly affecting our environment.

SUGGESTED REFERENCES

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